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ORIGINAL ARTICLE

An Investigation into the Couch Coefficient Accuracy of Exact IGRT Couch with Eclipse Treatment Planning System in Vital Beam Varian Linear Accelerator

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Abstract

Purpose: Posterior oblique beams are increasingly common in radiotherapy techniques. Radiation beams traversing through the treatment couch would be attenuated and cause under-dosage in the tumor region. The attenuation of an IGRT carbon fiber Couch for different angles, energies, field sizes, measurement points, couch regions, and the ability of the Eclipse treatment planning system to predict doses were investigated.

Materials and Methods: The Varian Vital Beam linear accelerator (Varian Medical Systems) and the Exact IGRT couch top, a new device for patient positioning, were utilized. The couch coefficient was calculated using in-air gantry angle measurements to determine the most attenuation angle. the attenuation measurements were performed in three measurement points of an inhomogeneous PMMA phantom using a farmer ionization chamber for three energies with six field sizes in three regions of an IGRT couch at the most attenuation gantry angle.

Results: The results of the couch coefficient measurements demonstrated that in three regions of the IGRT couch at an angle of 130˚, the photon beam was most attenuated. The difference between the calculated dose by the Eclipse treatment planning system and the experimental dose measurements was 1.855%. The difference is less than 3% and the attenuation was within the allowable range for treatment.

Conclusion: The IGRT treatment couch in posterior oblique gantry angles decreased the dose in the measurement points due to gantry angle, field size, energy, and couch region. The Eclipse treatment planning system can sufficiently predict the tumor dose distribution.

Keywords: Radiotherapy Treatment Couch; Exact Image-Guided Radiation Therapy Couch; Attenuation; Eclipse Treatment Planning System.

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1. Introduction

The Arc therapy technique emits radiation from different gantry angles to deliver the prescribed dose to the tumor while sparing the surrounding tissue. This technique reduces normal tissue complications and improves dose homogeneity in PTV and OARs [1]. In certain treatment planning, the rotation of the gantry transfers the beam to the couch before reaching the patient's body, causing beam attenuation [2,3]. Attenuation reduces the intensity of the beam and causes an under-dosage in the tumor. In fact, posterior oblique beams significantly attenuate due to the high density of metallic components in the treatment couches [4-7]. One of the critical considerations in rotation therapy is selecting the best material for the treatment couch with the least beam attenuation. Various couches from different companies with multiple details have been developed over the decades. [8]. Metallic support rails, side metal bars, metallic frames, and spine have been designed to produce strength in the earliest treatment couches [9-14]. The maximum attenuation reported for metallic frames was 60% [6]. Tennis-racket couches reduce beam attenuation and the risk of skin injuries. Nevertheless, they have two major deficiencies. The tennis racket region causes sagging during the treatment and the couch still has many large metallic parts (for example, rails). For this type of couch, the most significant attenuation of the 6 MV photon beam was 15% [15]. To prevent sagging the couch and obtain a more precise positioning of the patient, Carbon Fiber Couches (CFCs) have been presented. The advantages of carbon fiber make it an excellent material for radiotherapy tabletops [2]. Carbon fiber is a high-strength, rigid, lightweight material and could prevent sagging. Also, it has a low density which makes it radio translucent for megavoltage beams [16,17]. Different carbon fiber couches have been manufactured. These couches were made of two carbon fiber layers with foam material between two structural layers [18- 20].

Further research showed carbon fiber is a relatively high-density matter and it is not radio translucent. It makes significant attenuation and causes a reduction in dose distribution within the tumor [19, 21]. Furthermore, the attenuation beams were increased due to metallic connections inside the couch [17, 22]. The other disadvantages of carbon fiber include the reduction of build-up, an increase in surface dose, and the probability of skin effects [16, 17, 21]. One of the invented carbon fiber couches is IGRT (image-guided radiation therapy). The carbon fiber layer is thicker than the conventional models without metallic components. In these couches, the attenuation is much lower than the conventional technique [6]. Several articles have reported attenuation for posterior oblique gantry angles depends on energy, field size, gantry angle, and the location of the patient on the couch [20-23]. The important point of the couch is attenuation symmetry between gantry angles from 180 to 270 degrees [24]. There are two ways to reduce the magnitude of attenuation depending on a Treatment Planning System (TPS). There is no correction factor for oblique incidence and metallic components beam attenuation in some treatment planning systems [20]. The correction factor should be measured carefully and manually applied to the treatment planning Monitor Unit (MU) calculations to compensate for the beam attenuation. Commonly the treatment planning systems do not consider the treatment couch [2, 7, 22]. Modeling the treatment couch in the CT image is an excellent way to optimize dose calculations for couch attenuation in the treatment planning system [22-24].

In this study, we evaluated the effect of carbon fiber tabletop at varying posterior oblique gantry angles, field size, and photon beams to investigate the attenuation and any difference between measured and calculated attenuation by the treatment planning based on the IGRT couch.

2. Materials and Methods

In this research, measurements were performed on the Vital Beam linear accelerator (Varian Medical Systems, Palo Alto, CA, USA) with 6 MV, 15 MV, and 18 MV photon beam energies. The Exact IGRT couch top (Varian Medical Systems, Palo Alto, CA) is constructed of carbon fiber shell and low-density foam materials with variable thickness. This type of couch is divided into three distinct areas: the pelvis region (thick), thoracic region (medium), and neck region (thin). The couch thickness for two regions (thick and thin) is constant.

An inhomogeneous PMMA phantom (Behyaar Sanaat Sepahan, Isfahan, Iran) was used for central axis (CAX) attenuation dose measurements. The phantom consists of 12 plates, with a dimension of 356×210×24 mm^3. The plates contain cavities located at eight places for a Farmer-type ion chamber. The details of the phantom are shown in Figure 1.

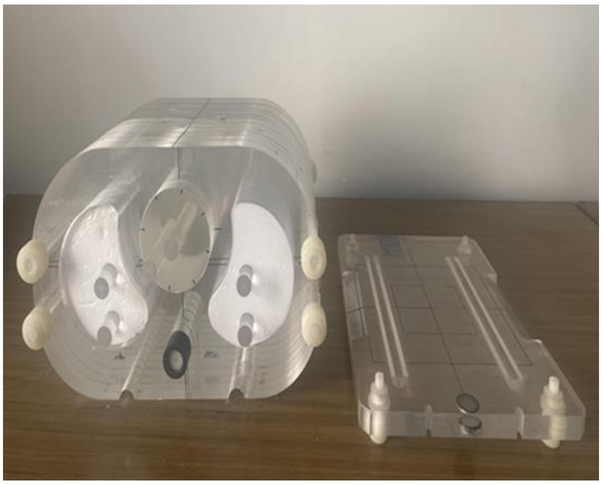


Figure 1. The thoracic phantom

A farmer-type ionization chamber (TM30013, PTW, Freiburg, Germany) was inserted within the phantom and connected to a Unidos electrometer (T10008, PTW, Freiburg, Germany) to measure the absolute dose. The center of the chamber was positioned at the linac's isocenter. The phantom was scanned with Neusoft CT Scan with a slice thickness of 5 mm, 30 cm long, FOV=50 cm, and tube voltage of 80 kV. The Aria R&V system imported the images with DICOM format to the Eclipse TPS version 15.2 (Varian Medical Systems, Palo Alto, CA, USA). Different parts of the phantom and the couch were contoured. The contour was created for the lungs, heart, and spine. In the last part, the contoured couch model was added to the organ model. The Eclipse TPS provides three simplified models of the IGRT couch top (thin, medium, and thick regions).

2.1. Measurements

2.1.1. The Most Attenuation Angle

To determine the most attenuation angle, the couch coefficient was calculated using in-air gantry angle measurements by Equation 1. This process was performed for three-photon energies and three regions of the couch. The gantry angle with the lowest couch coefficient has the most attenuation angle.

$$\text{couch coefficient} = \frac{\text{electrometer reading with the presence of the couch}}{\text{electrometer reading without the presence of the couch}} \quad (1)$$

The ionization chamber was covered with different build-up caps for each photon energy. According to Figure 2, the chamber and build-up cap were positioned in the thin (a), medium (b), and thick (c) regions of the couch at the isocenter.

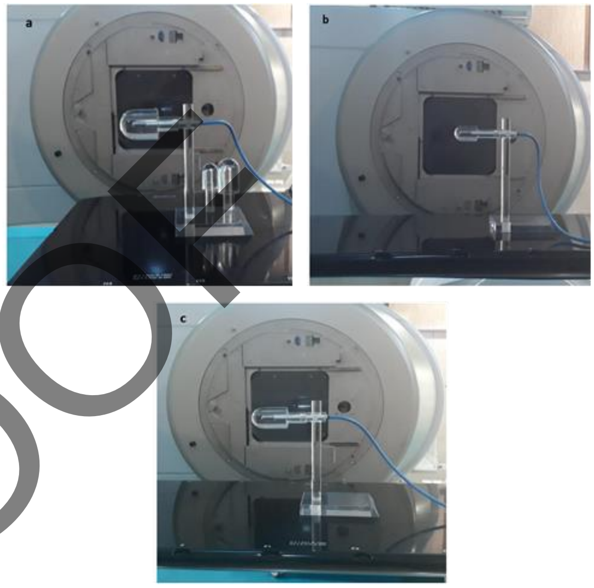


Figure 2. Chamber positioning for the numerator of the couch coefficient at 90˚ for three regions: (**a**) thin, (**b**) medium, and (**c**) thick regions of the couch

Previous research [19, 24] has shown that the angular dependence exhibits symmetry. Consequently, our measurements were performed at gantry angles from 90 ˚ to 180˚. The gantry angle was set at 90 ˚ and then rotated through angles from 90˚ to 180˚ in steps of 10˚. This process was repeated for the medium and thick regions, and the numerator of the couch coefficient was obtained. An in-air measurement with three energies was performed for regions of the couch to make the denominator of the couch coefficient (Figure 3).

Finally, the couch coefficient was calculated by Equation 1, and the most attenuation angle was obtained.

Figure 3. Chamber positioning for the denominator of the couch coefficient

2.1.2. Dose Calculation by the Ionization Chamber

At the highest attenuation gantry angle (Figure 4), the dose measurements were performed for six field sizes (3×3, 6×6, 10×10, 15×15, 20×20, and 30×30cm^2), three-photon energies (6 MV, 10 MV, and 15 MV), three couch regions (thin, medium, and thick), and three measurement points (soft tissue, spine, and lung).

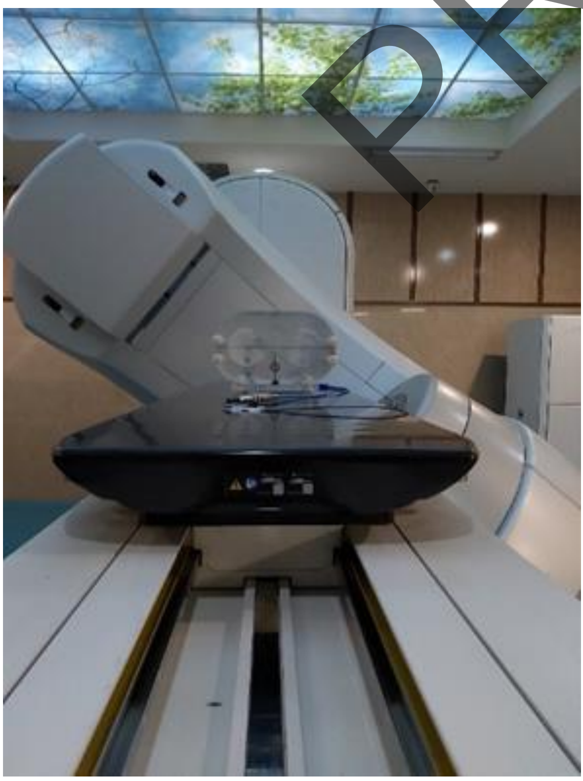


Figure 4. Phantom positioning for measurements

The phantom was placed in the thin region of the couch, while the chamber was located within the lung measurement point. The energies and field sizes were changed, and measurements from the electrometer were documented. This process was repeated for two other measurement points (soft tissue and spine) and couch regions (medium and thick). To compare the results, ionization chamber measurements were converted to absorbed dose (cGy) using the IAEA TRS-398 guidelinesIn.

2.1.3. Dose Calculations by the Eclipse TPS

In the last step, we evaluated the accuracy of dose calculation by Eclipse TPS based on the Anisotropic Analytical Algorithm (AAA) for 162 treatment planning. To investigate the received dose to three points (soft tissue, spine, and lung), the dose distribution in three regions of the couch, three-photon- energies, and six field sizes was calculated.

3. Results

The results of the couch coefficient measurements for three regions of the treatment couch with different photon energies are summarized in Tables 1-3.

Based on the results, the most attenuation angle was 130º. Figure 5 demonstrates the variation of the couch coefficients in three regions of the couch (thin (a), medium (b), and thick (c)) with different gantry angles for three-photon energies. The dose was normalized to the ion chamber reading at the 0° irradiation.

The difference between the calculated dose by the Eclipse treatment planning system and the experimental dose measurements for six field sizes, three regions of the couch ((a) thin, (b) medium, and (c) thick), and three measurement points (soft tissue, spine, and lung) are shown in Figures 6-8.

If the difference between the two numbers is less than 3%, the attenuation is within the allowable range for treatment. The point dose attenuation varies from 0.39% to 2.58%, 0.49% to 2.57% and 0.06% to 2.16% for 6 MV, 10 MV, and 15 MV photon beam energies, respectively. The difference between calculated and measured point doses varies from 1.173% to 1.855%, 1.098% to 1.496%, and 0.899 to 1.634% for 6 MV, 10 MV, and 15 MV, respectively. The most significant point dose attenuation and the difference between the

Table 1. The couch coefficients(±SD) for the thin region of the couch

ANGLE (Degree)	90	100	110	120	130	140	150	160	170	180
Energy 6MV	1.0049 ±0.0008	1.0062 ±0.0007	1.0031 ±0.0003	1.0031 ±0.0002	0.9652 ±0.01	0.9714 ±0.01	0.9739 ±0.009	0.9764 ±0.007	0.9776 ±0.009	0.9757 ±0.01
Energy 10MV	1.0012 ±0.0001	1.0012 ±0.0001	1.0012 ±0.0001	1.0012 ±0.0001	0.9758 ±0.01	0.9825 ±0.01	0.9867 ±0.008	0.9897 ±0.009	0.9909 ±0.01	0.9909 ±0.01
Energy 15MV	1.0023 ±0.0002	1.0029 ±0.0006	1.0035 ±0.0002	1.0035 ±0.0002	0.9802 ±0.01	0.9874 ±0.01	0.9916 ±0.01	0.9940 ±0.007	0.9952 ±0.008	0.9952 ±0.008

Table 2. The couch coefficients(±SD) for the medium region of the couch

ANGLE (Degree)	90	100	110	120	130	140	150	160	170	180
Energy 6MV	1.0006 ±0.0001	1.0006 ±0.0001	1.0006 ±0.0001	1.0000 ±0.004	0.9621 ±0.008	0.9671 ±0.008	0.9689 ±0.009	0.9720 ±0.007	0.9739 ±0.006	0.9751 ±0.01
Energy 10MV	1.0012 ±0.0001	1.0000 ±0.004	1.0000 ±0.003	1.0000 ±0.004	0.9734 ±0.01	0.9794 ±0.009	0.9819 ±0.009	0.9849 ±0.01	0.9873 ±0.01	0.9879 ±0.01
Energy 15MV	1.0059 ±0.001	1.0059 ±0.002	1.0065 ±0.003	1.0065 ±0.008	0.9879 ±0.01	0.9957 ±0.009	0.9981 ±0.008	1.0018 ±0.001	1.0036 ±0.001	1.0054 ±0.001

Table 3. The couch coefficients(±SD) for the thick region of the couch

ANGLE (Degree)	90	100	110	120	130	140	150	160	170	180
6	1.0068 ±0.001	1.0055 ±0.0007	1.0049 ±0.0004	1.0055 ±0.0009	0.9608 ±0.002	0.9646 ±0.009	0.9671 ±0.007	0.9708 ±0.003	0.9720 ±0.002	0.9733 ±0.005
10	1.0024 ±0.0004	1.0030 ±0.0004	1.0036 ±0.0004	1.0036 ±0.0004	0.9728 ±0.003	0.9788 ±0.009	0.9819 ±0.004	0.9849 ±0.002	0.9873 ±0.001	0.9855 ±0.0005
15	1.0071 ±0.0005	1.0077 ±0.0002	1.0083 ±0.0003	1.0089 ±0.0004	0.9802 ±0.002	0.9868 ±0.001	0.9904 ±0.0006	0.9934 ±0.003	0.9952 ±0.001	0.9958 ±0.0004

treatment couch's calculated and measured point doses were detected at 2.58% and 1.855%, respectively. According to these data, the difference values in all situations are within the allowable range.

4. Discussion

Rotational therapy utilizing different gantry angles is used to treat local tumors with fewer complications [3, 20]. However, the beams may pass through the couch at posterior oblique angles and reduce the accuracy of dose calculations. Nowadays, carbon fiber couches are used with less attenuation than the earliest treatment couches [18, 20].

This study aims to evaluate the rate of the beam attenuation at the Exact IGRT couch in oblique angles and compare the allowable range of 3% for the difference between the measured dose by the chamber and the TPS calculated dose. The attenuation values obtained by the chamber showed conflicting results with the study of Viera *et al*. [15]. Their study was performed to determine the attenuation rate with EPID for an Exact couch and by Clinac 2300 linear accelerator. Due to the presence of a metal rail in the beam path, the maximum attenuation in head and neck treatment was obtained at 15% in posterior oblique fields with 6 MV energy. In contrast, the results of the present study showed that the highest attenuation rate at 6 MV energy for different field sizes, phantom points, and couch regions was obtained at 2.58%. The different results between the present study and the Viera study may be due to using the various couches.

An Exact IGRT couch is a newer type of radiation therapy couch with advantages such as the absence of metal rails compared to the Exact couch. In general, the IGRT couches are the latest treatment couches with the lowest radiation absorption among the types of couches. According to previous articles, the

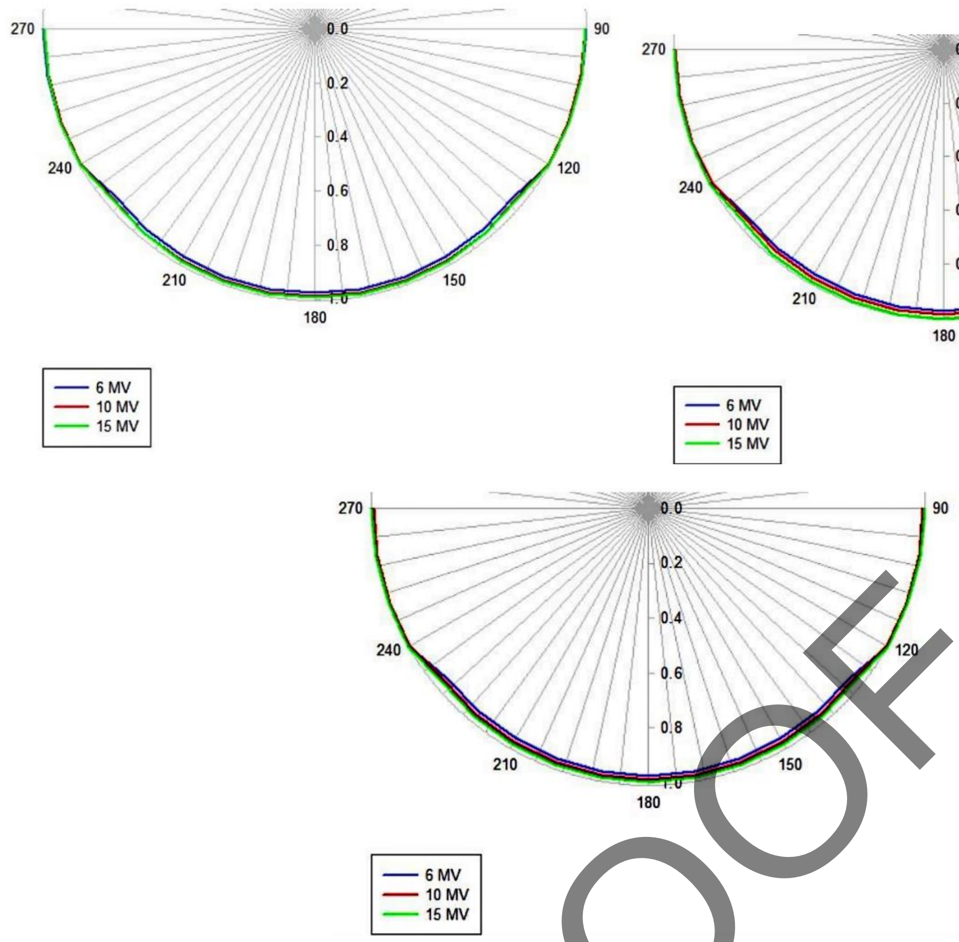
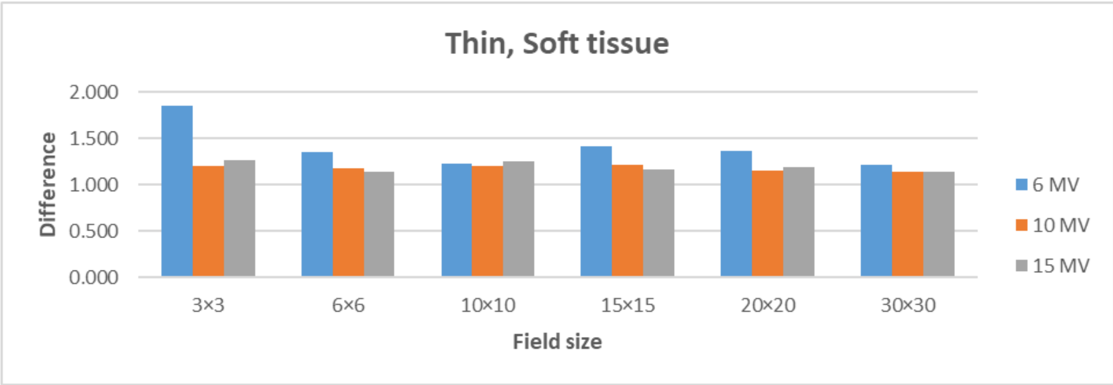


Figure 5. The chart of couch coefficients for **(a)** the thin, **(b)** medium, and **(c)** thick regions of the couch.

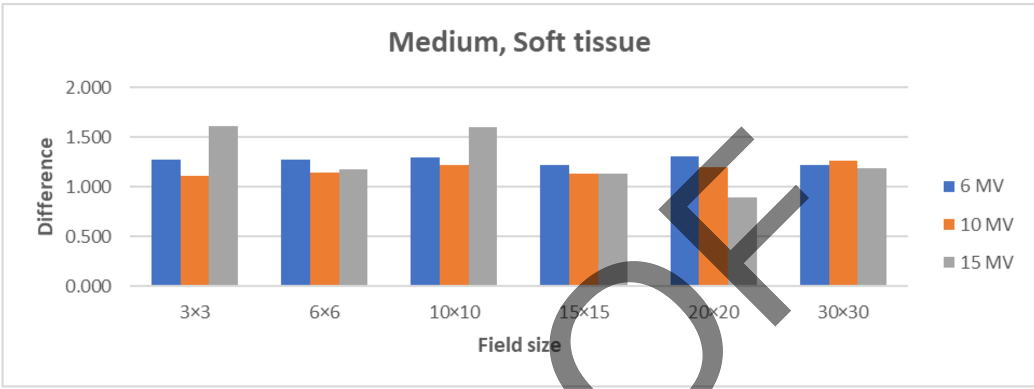
IGRT couches reduced attenuation in the IMRT technique [5].

In the study by Myint *et al* [2], the attenuation of 6 and 18 MV photon beams of Mevatron accelerator in a cubic phantom passe through a Medtec couch at posterior oblique gantry angles were evaluated. The attenuation changed up to 6.8% with different energies and field sizes making the tumor uncontrollable. In the current study, the attenuation results were less (maximum attenuation is 2.58%) than the results of the Myint study. Therefore, dose reduction did not occur in the tumor, and the tumor control probability was higher. In another study by McCormack *et al.* [17], the attenuation of a Sinmed couch with a cylindrical phantom at different angles of an SLi linear accelerator for 6 MV beams was investigated. The attenuation increased with increasing gantry angle due to increasing beam thickness through the phantom from 2% to 9%. In the current study, the increased attenuation was observed with the increase in gantry angle (due to an increase in the thickness of the phantom or carbon fiber layer).

In the studies of Myint *et al.* [2] and Vanetti *et al.* [25], there was a possibility that the treatment plan was rejected due to the different doses with and without couch in the beam path. In the recent study, the attenuation values were below 3% (beam transmission above 97%) and none of the 162 plans were rejected. Sheykhoo *et al.* [1] investigated the effect of 550 TXT couch on the attenuation of 6MV photon beams from Primus linear accelerator in a water phantom. Based on this study, carbon fiber couches were not radio translucent and the beam transmission coefficient should be measured in different conditions. In the present study, the non-radio translucent properties of carbon fiber couches were confirmed. In the research of Vanetti *et al.* [25] on an IGRT couch, the interesting point was the symmetry in attenuation for the 360-degree rotation of the gantry. In this study, this point was used for the Exact IGRT couch, and angles



(a)



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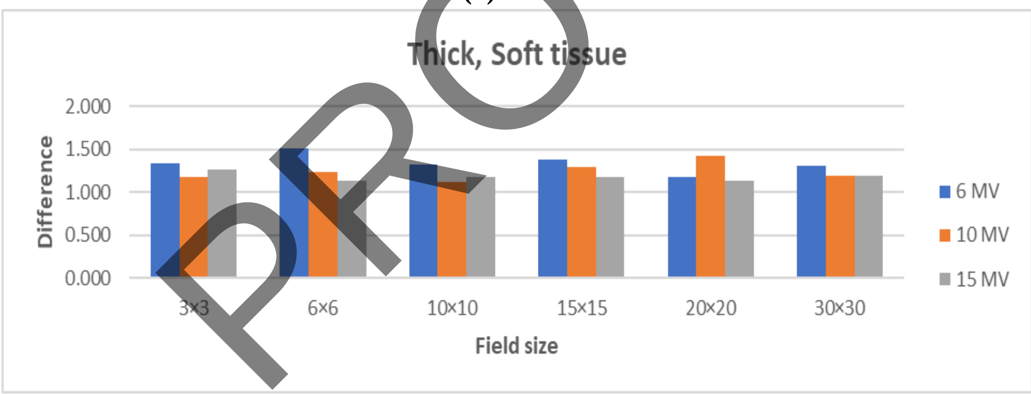


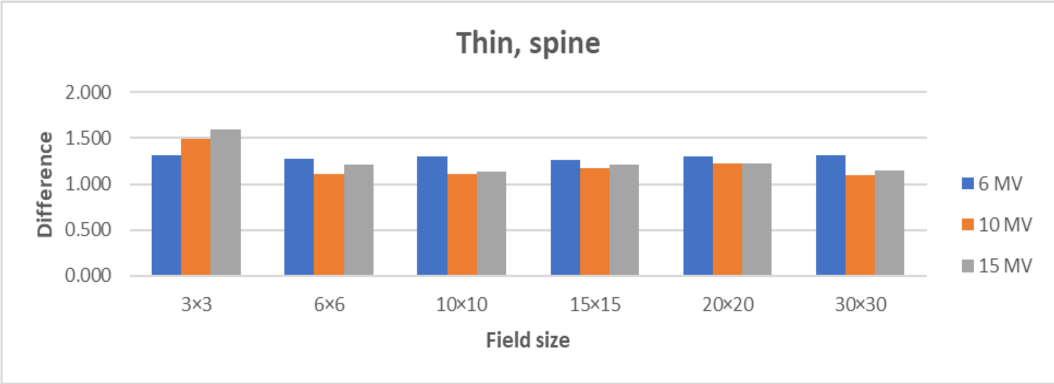
(c)

Figure 6. The difference between the calculated and measured dose in **(a)** the thin, **(b)** medium, and **(c)** thick regions of the couch, and the soft tissue point

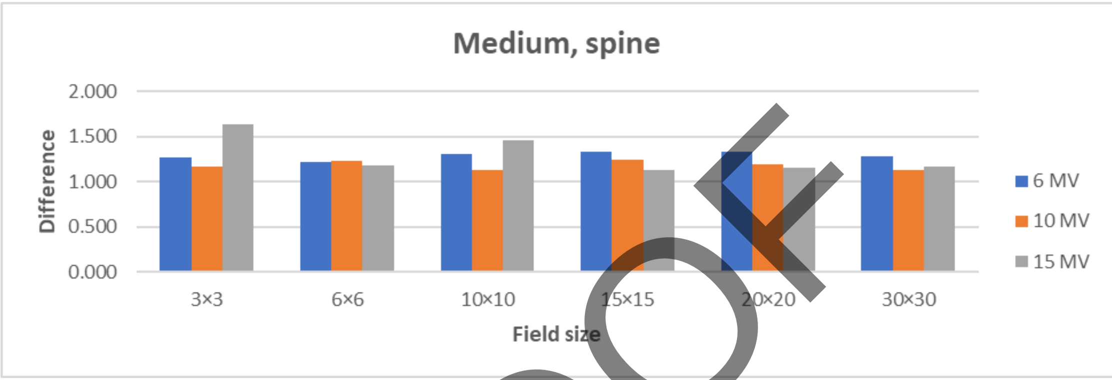
between 90 and 180 degrees were investigated.

Njeh *et al.* [26] used different gantry angles for 6 and 18 MV energies in the phantom to evaluate the attenuation of a BrainLAB couch. They reported that the increased attenuation was affected by the increased gantry angle. Therefore, there are similarities between the results of the current study and the results of the Njeh study, in which attenuation develops with increasing gantry angle. Vanetti *et al.* [25] conducted a study to model an IGRT couch with 6 and 15 MV for iX linear accelerator using the Eclipse TPS. The most significant attenuation was reported in the gantry angle of 225 degrees with a value of 4.4%. In the present study, for the Exact IGRT couch, the maximum attenuation at an angle of 130 degrees (and 220 degrees) was 2.58%.

One of the concerns in our study was the difference between the measured dose and the calculated dose by TPS at posterior oblique gantry angles. Pulliam *et al.* [7] used 6 MV energy of a Varian linear accelerator on the Exact couch. They found a significant difference



(a)



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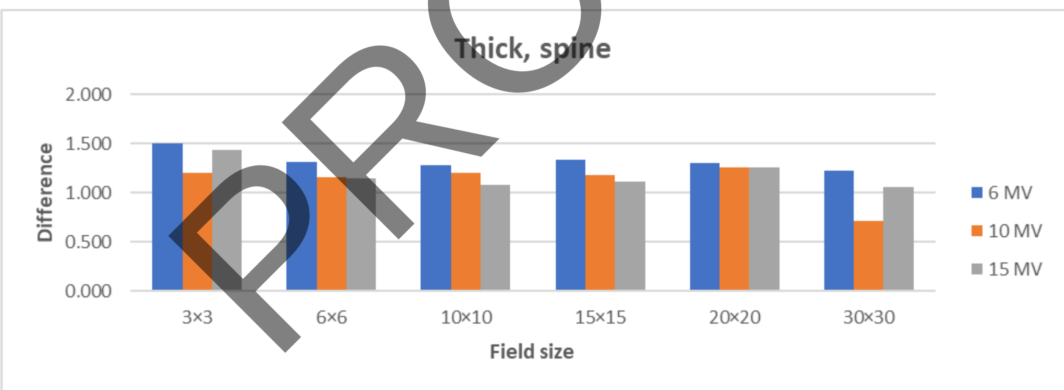
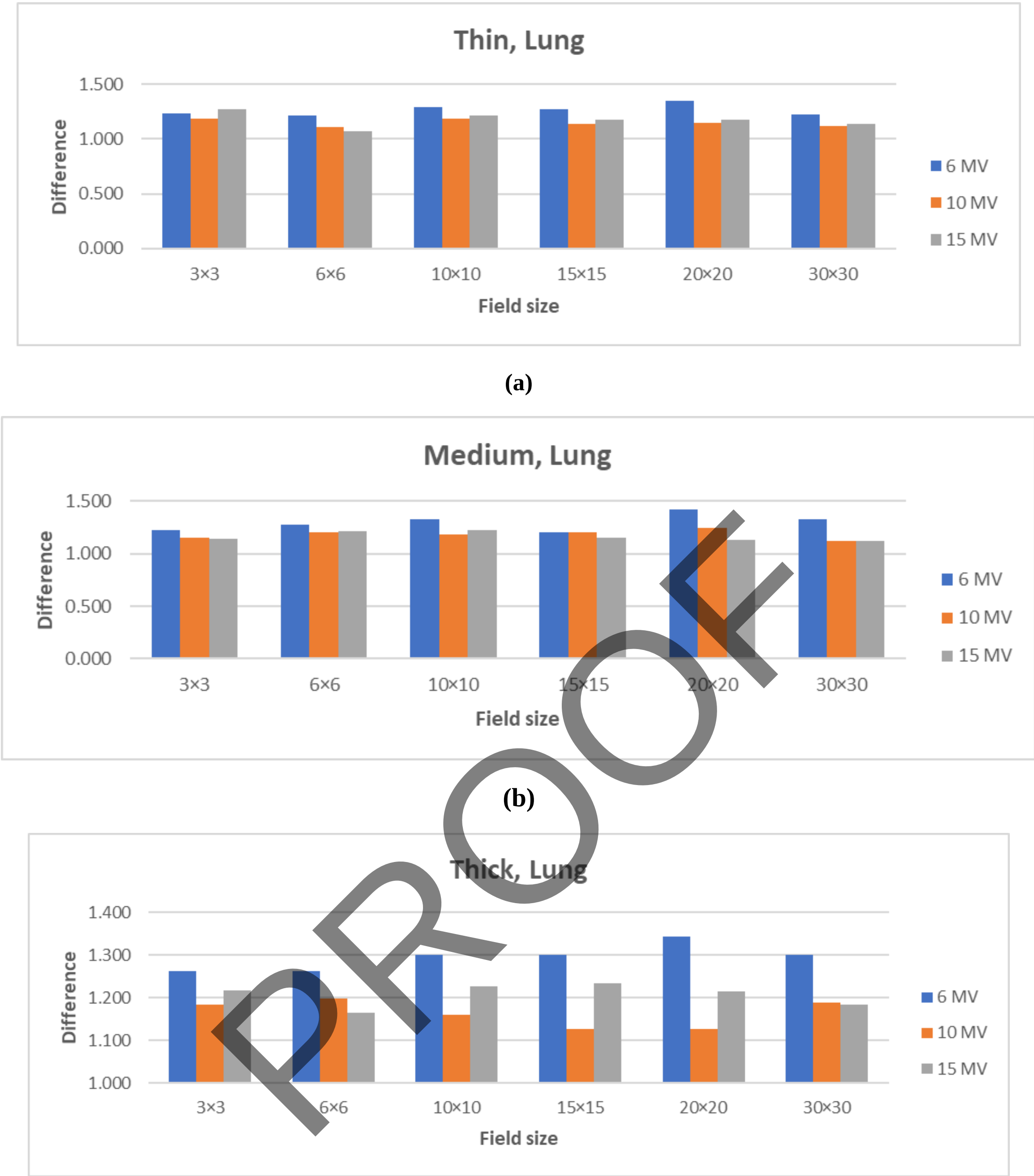


(c)

Figure 7. The difference between the calculated and measured dose in **(a)** the thin, **(b)** medium, and **(c)** thick regions of the couch, and spine

between measured doses with and without the couch in the beam path out of the allowable range. They designed the couch with the Eclipse TPS and reduced the difference up to 0.7%, which increased the accuracy of treatment planning. In the present study, the attenuation was obtained less than the allowable range of 3%. The attenuation will be less if the attenuation information of 162 measurement points in different conditions is added to the TPS.

In some cases, we expected the difference to be excessive, but different results were obtained. One of the reasons was a single couch coefficient used for dose calculations in treatment conditions in TPS. The attenuation coefficient was obtained at an angle of 180 degrees when auditing the machine by the



(c)

Figure 8. The difference between the calculated and measured dose in **(a)** the thin, **(b)** medium, and **(c)** thick regions of the couch, and lung point

manufacturer. Therefore, if radiation therapy centers define couch coefficients in the TPS, a significant part of the attenuation is calculated by the software, and the attenuation of photon beams is reduced. the difference would exceed the allowable range if the IGRT couch had metal parts or high-density materials.

Another reason was the treatment couch and CT couch identical. When taking a CT scan of the phantom, a CT scan of the couch was taken. All dose calculations performed in TPS were based on CT image information (CT number and calibration curve) transmitted to TPS. Hence, as the two couches were identical, accurate dose calculations were performed. The present study results evaluate the attenuation of photon beams at gantry angles between 90 and 180 ° for the Vital Beam linear accelerator and Exact IGRT couch. The importance of the beam passing through posterior oblique angles from the couch due to increasing carbon fiber thickness in changing the absorbed dose determined. It was shown that the dose attenuation values (with a maximum value of 2.42%) and the difference between the measured dose and the calculated dose (with a maximum value of 1.855%) did not exceed the acceptable range of 3%.

The maximum attenuation was in the conditions of 6 MV energy, the field size of 3×3 and the thick region of the couch, and the maximum amount of difference between the measured dose and the calculated dose was in the conditions of 6 MV energy, the field size of 3×3 and the thin region of the couch. These data are consistent with the hypothesis of increased attenuation in smaller field sizes, thicker regions, and lower energies. The difference between measured and calculated doses differed only in 4.32% of the 162 measurement points above 1.5% to 1.855%, which means the difference was insignificant in more than 95% of the obtained data. The most important effect was the attenuation of the 130-degree gantry angle, which could be the source of error in the posterior oblique areas.

Based on the results, the dose delivery error in the posterior oblique angles is decreased with inserted information of the treatment couch attenuation to the TPS. The results of determining the angle with the highest attenuation showed that although all the measurements were within the acceptable range, the attenuation was more significant at more oblique angles.

5. Conclusion

In this study, the attenuation of photon beams transmitted at the most attenuation angle was investigated under different measurement conditions. Based on the results, the most significant difference between TPS calculations and measurements was less than the allowable range. Therefore, dose distribution by the Eclipse TPS for the Exact IGRT couch can be predicted.

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